(54) PROCESS AND APPARATUS FOR HIGH ENTHALPY HEAT TREATMENT

(71) We, IONARC SMELTERS LTD. (N.P.L.), a company incorporated under the laws of the Province of British Columbia, Canada, of 850 West Hastings Street, Vancouver, British Columbia, Canada, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a process and an apparatus for high enthalpy heat treatment and is specifically, but not exclusively, concerned with the winning of metals from ores in one or a plurality of stages.

The scope of this invention is necessarily very wide as the technique described herein is applicable to the production of many metals and also to many other chemical reactions.

Throughout this specification and claims, by "high enthalpy thermal environment" is meant an environment wherein an average temperature in the general range 4000°C—8500°C, is maintained, for example in a high intensity plasma arc, in contrast to a glow discharge or a silent arc discharge (generally referred to as a non-transferred arc), or a "cold atom" reactor. A "high intensity arc" is in turn defined as an electric arc, with a tail flame, between at least two electrodes at least one of which includes carbon-containing material, which arc has a positive electrical resistance characteristic, that is an increase in current is accompanied by an increase in voltage across the arc. In one preferred embodiment, this high intensity arc is obtained by an arc struck between two graphite electrodes which are overpowered so that the electrodes are at least partially vaporized and consumed. A "tail flame" is characteristic of a high intensity arc and such an arc in a diatomic gas will generate temperatures of the order 4000—8500°C with relatively low gas velocities compared with gas velocities in arcs of the "non-transferred" type. The high intensity arc condition can also be

obtained in other arrangements, for example an arrangement in which an anode is porous and a gas is supplied to the arc region through the pores of the anode.

There are many known methods for the production of metals from their ores, and a large number of them is pyrometallurgical in nature. Some metals are relatively easily won from their ores, for example copper and iron, while others are won with extreme difficulty, for example titanium and zirconium. The ease of extraction is naturally reflected in the availability and price of the metal. As technology advances, the demand for metals such as niobium, tantalum, zirconium, and titanium grows, and many efforts are therefore being made to extract those metals more economically.

According to the present invention in one broad aspect, there is provided a process for heat treating a non-gaseous material including providing a controlled atmosphere, establishing a high enthalpy thermal environment (as hereinbefore defined) in said atmosphere by means of at least one high-intensity arc (as hereinbefore defined), the or each said arc having an elongated tail flame forming part of said environment, feeding said material in powder form into said controlled atmosphere for passage through, and with a sufficient residence time in, said environment to affect the material by the heat therein, and allowing the material to pass from said environment through a cooling atmosphere to a collection zone.

Said electrodes are preferably energised by a.c., though d.c. may also be employed.

Advantageously, a plasma carrier gas may be injected into said high enthalpy environment.

Said material may be suspended in said carrier gas for introduction into said high enthalpy environment.

Preferably, the suspension of said material in said carrier gas is injected into a low-

intensity plasma to produce an at least partially ionized stream of gas containing said suspended material before being introduced into said high enthalpy environment.

5   Said low-intensity plasma stream is preferably introduced between a pair of spaced electrodes, the gap between the electrodes being supplied with a second carrier gas.

The heat treatment of said material may
10 produce one or more of the following chemical reactions: the conversion of metal oxides to metal; of metal oxides to metal halides; of metal halides to metals; or the dissociation of complex minerals to simple compounds, and
15 said material may be an ore, a concentrate, or a residue.

According to another aspect of the present invention, there is provided apparatus for carrying out the process set forth above, said
20 apparatus including a chamber for containing a controlled atmosphere, means for establishing at least one high-intensity arc (as hereinbefore defined) to establish a high-enthalpy thermal environment in said atmosphere, means for
25 feeding a non-gaseous material into said environment, and means permitting the said material to pass from said environment through a cooling atmosphere to a collection zone, the or each said arc being produced
30 between spaced electrodes, there being electric power means for energising said electrodes to produce the or each said arc, at least one of the said electrodes including carbon-containing-material.

35   The apparatus may include means for cooling the material after its passage through said high enthalpy environment and prior to its entry into said collection zone.

Said power means preferably includes an
40 a.c. power supply for energising said electrodes to produce the or each high intensity arc discharge.

For stabilising said arc(s), there may be provided means for superimposing a high volt-
45 age, high frequency, low amperage current on the power supply.

Thus it will be seen that in one particular process of this invention the high enthalpy thermal environment may be established in a
50 halogen or halide containing atmosphere and platinum-containing ore in particulate form is introduced through the arc to provide a chemical reaction making the platinum more amenable to separation by known commercial
55 techniques. In another specific process, the high enthalpy environment is established in a reducing atmosphere and ore containing nickel and cobalt is introduced through the arc into the high enthalpy zone producing a
60 chemical reaction that makes the metals more amenable to recovery by commercial techniques.

Broadly, therefore, the present invention enables improved utilization of ores, since
65 when ores or concentrates are normally pro-

cessed for the extraction of the primary metal content, the gangue material which usually consists of oxides and silicates of such metals as iron, aluminium and magnesium and which
70 may constitute a high percentage of the total weight is recovered as a metallurgical slag or other form of waste residue. In the process described herein, increased amounts of mineral compounds, metal values and gangue minerals
75 can be altered and reformed into pure stable compounds of commercial value, for example Al_2O_3, MgO, amorphous SiO_2 or metallic Al and Mg in addition to the primary metal.

The invention will now be described, by
80 way of example only, with reference to the accompanying drawings in which:

Figure 1 is a graph of typical arc discharge regimes,

Figure 2 is a diagrammatic sketch of one
85 embodiment of the apparatus used for the process of the present invention,

Figure 3 is a diagram of a system incorporating the apparatus shown in Figure 2,

Figure 4 is a schematic flow diagram for
90 the process of one preferred embodiment of the present invention, and

Figure 5 is a schematic flow diagram of the embodiment of the invention shown in Figure 4 with certain of the electrical requirements.

95   As previously indicated, the present invention is concerned with high enthalpy thermal environments established by one or more high intensity arcs. The various forms of arc discharge are substantially defined in Figure 1
100 which is a diagrammatic graph showing typical discharge regimes in relation to current density and pressure/field strength and which is based on the publication "Chemical Kinetics of Gas Reactions" by V. N. Kondrat'ev, published by
105 Addison and Wesley 1964. Such high intensity arcs are produced at very high current densities in contrast to a silent discharge, for example, which is produced at low current densities.

Referring now to Figures 2—5, there is
110 shown an arc furnace according to the present invention, together with some of the ancillary equipment associated with it.

The furnace, shown generally at 1, comprises a reaction chamber 2, preferably con-
115 structed of a corrosion resistant material such as stainless steel, into which electrode holders 3 and 4 project through gas sealing rings 5 and ceramic insulating discs 6 located in a lid 12. Electrode holders 3 and 4 are preferably fluid
120 cooled via inlets 7 and outlets 8, and depending on the power supply contemplated can be fabricated from any good electrical conductor such as tungsten, copper-tellurium, copper, aluminium or various combinations thereof.
125 Electrode holders 3 and 4 are adapted to be adjusted both vertically and horizontally in order to maintain optimum electrode spacing during operation. Graphite electrodes 9 are held in holders 3 and 4 by known means, such
130 as clamping or screwing, and during operation

a main high-intensity arc 15 is generated between the tips of the electrodes 9 to create a high-enthalpy zone. The arc 15 has a tail flame 16 which is characteristic of high-intensity plasma arcs, achieved by overpowering (i.e. supplying excessive power to) the electrodes 9 so that the tips of said electrodes at least partially vaporize in a self-cleaning operation and also provide carbon which may act as a reductant for the feed materials or may merely escape as an oxide of carbon. Thus in the arc 15 the electrodes 9 are consumed; and the arc 15 has a positive electrical resistance characteristic, as hereinbefore discussed. Graphite electrodes are the most suitable for this application, but in certain circumstances other carbon-containing electrode materials which would not contaminate or interfere with the described reactions could be used.

Power is supplied to the electrode holders via power leads 10 and 11 from a power source 53 (Figures 4 and 5). Either a.c. or d.c. power sources are contemplated by the present invention, depending on the type of material being treated, and on the specific electrode configuration and power supply available. In the embodiment shown in Figure 2 an a.c. supply was found suitable, and was conveniently about 55 volts and 1150 amps at 400 Hz. With this power supply it was found that difficulties encountered in maintaining a stable arc at a suitable electrode spacing for the introduction of feed could be at least partially overcome by superimposing a high voltage, low amperage, high frequency current on the main power supply. Typically, a 6 kW 5mHz current may be employed. Alternatively, or additionally, at least a portion of a carrier gas may be pre-ionized before passing between the main electrodes 9, thereby ensuring a continuous conducting path for the main power supply. The said carrier gas is conveniently pre-ionized in a pre-ionizing unit 14 also mounted in lid 12. In Figure 2 this unit 14 is shown above electrodes 9 for convenience, but it will be appreciated that this furnace may be operated in a horizontal plane as well as in a vertical plane.

The pre-ionizing unit 14 comprises an earthed control head 17 mounted through ceramic disc 6 and equipped with external water cooling coils 18. An annular water cooled electrode 19, preferably of tungsten, forms the lower end of control head 17. An electrode 20, also preferably of tungsten, is mounted in a holder 21 vertically above the annulus of said electrode 19, and is equipped with a height adjusting knob 22 which is adapted to rotate holder 21 in the threaded portion 23 to adjust the position of electrode 20. Power is supplied to electrode 20 via a lead 24 from a power supply (not shown). An arc is struck in operation between electrodes 19 and 20 and a gas, preferably but not essentially an inert gas, is passed through the arc

zone 25 from inlet 26 generating a low intensity plasma 30. Argon or nitrogen are particularly suitable gases in the pre-ionizing unit 14. Fluid cooling is provided to electrode 19 via inlets 27 and outlets 28. When the arc zone 25 is stabilised, a carrier gas is introduced to the pre-ionizing plasma 30 via inlets 29. The pre-ionized gas stream 30 is focused above the main electrodes and the partially ionized gases are carried into the main high intensity arc 15 generated between the tips of the electrodes 9. When the pre-ionizing plasma stream 30, the main arc 15 and the tail flame 16 are stabilized, the ore feed is started and the ore is introduced into the furnace or chamber via inlets 29 mixed with a high intensity plasma carrier gas, which may be inert but is more usually a reactant gas such as natural gas, air or hydrogen. Ore, or other powdered reactants, is stored in a feed hopper 31 which is provided with a feeder 57 (Figure 5) which may be a rotary valve device 32 (Figures 3 and 4), to draw feed material from the hopper at a steady, controlled and predetermined rate.

After passing through the pre-ionized low intensity plasma 30, the main arc 15 and the tail flame 16, the reactants are cooled in the reaction chamber 2. Chamber 2 includes a parallel side portion 35 and a frusto-conical tapering section 36 with an outlet 37, and may include external and internal controlled cooling means such as water sprays or gas coolant jets (not shown) to control the temperature at various levels in the reaction chamber. It is necessary that the reaction chamber shall be of sufficient volume to contain the plasma tail flame 16 and to permit sufficient residence time to complete the reactions, and to effect a sufficient degree of cooling. A high efficiency wet scrubber 38 (Figure 3) may be connected directly to the outlet 37 of the reaction chamber. This scrubber has the three-fold purpose of removing heat from the effluent, both gaseous and solid, collecting solid products and taking into solution soluble products of the chemical reactions. Optionally an additional collection circuit including a magnetic separator (diagrammatically indicated at 40) and a baghouse 42 may be employed.

In the embodiment shown in Figures 2 and 3 a single pair of electrodes is employed, but it will be appreciated by those skilled in the art that a plurality of electrodes may be employed. Basically the operation of such embodiments is the same as that of Figures 1 and 2 and may be operated on a.c. or d.c. power supply.

In operation, feed material such as an ore is prepared by reducing the particle size to about 100% through 30 mesh, by any of the standard ore dressing techniques and followed by complete drying.

The prepared feed is stored in the feed hopper 31 having a uniform controlled discharge rate, metered through a system of

rotary valves 32 or similar devices which serve as a gas seal to prevent blow-back of furnace gas, and then directed to a mixer device 34 where it is mixed with a carrier gas which enters via inlet 33. The carrier gas may be relatively inert, for example, nitrogen or argon or it may be one of the reactants for example, chlorine, carbon monoxide, air or oxygen, depending on the desired reactions. In the embodiments of the apparatus shown in Figures 2 and 3 the feed and carrier gas are injected via inlets 29 into the plasma stream 30 produced by the pre-ionising unit 14 which conveniently is an a.c. plasma torch typically generating a flame about 1/4″ in diameter and 1″ long with a 10 KW power supply.

The feed materials are thus suspended in a partially ionized gas stream which is then directed into the high enthalpy thermal environment of main arc 15 and tail flame 16, produced by over-powering graphite electrodes 9 which are connected to a 400 cycle a.c. power source (not shown). It has been found that the pre-ionized gas stream is desirable to maintain an electrical path between the graphite electrodes, but that if the electrode spacing is increased, for example in order to increase the feed, the circuit may be broken and the arc extinguished. In order to prevent this and to ensure continuous operation of the arc a five megacycle current from an oscillator may be connected across the graphite electrodes 9. This high voltage, low amperage current provides an ever present ionized path across the electrodes for the 400 cycle current. Alternatively, a relatively low voltage direct current may be applied across electrodes 9 in which case the superimposed high frequency current is unnecessary to prevent extinguishment of the arc. Other methods for stabilizing the arc will readily suggest themselves to those skilled in the art. Power input to electrodes 9 can vary over a wide range and electrode diameter may also vary with the power input in order to maintain a high current density at the electrode face, sufficient to produce a positive resistance characteristic on the main arc 15. When multiple electrodes are employed, pre-ionizing of the carrier gas and preheating of the feed may not be necessary and therefore in some cases the pre-ionizing unit may be omitted. Similarly it may not be necessary to apply a superimposed current on the main arc current in order to stabilize the arc.

As those skilled in the plasma arc art will readily appreciate, the tail flame generated in a high intensity plasma torch using consumable electrodes can be up to 18 inches long at 50 KW or even longer, depending on the power available and may be as hot as 8,000—10,000°C at the base. The flame is of relatively low velocity and therefore it is possible to obtain extremely long retention times for materials passed through the flame. Furthermore, the degree of ionization in the tail flame of a high intensity plasma may be as high as 10—40% in contrast to a low intensity arc where the ionization rarely exceeds 5%. In this highly energetic state the free ions recombine according to the normal laws of kinetics and thermodynamics to seek the lowest energy state. Some reactions may take place in the very high temperature plasma zone but others may take place as the reactants cool below the dissociation temperature of the desired product on leaving the high enthalpy zone. In many instances the free metal may be produced, while in others, from complex starting materials, simple metal compounds are produced which can then be extracted by standard pyrometallurgical or hydrometallurgical procedures. In yet other cases, a metal compound may be formed which is amenable to a further treatment through the plasma zone under a different processing environment to produce the free metal in a two stage process.

The plasma tail flame from the high intensity arc is directed into the reaction and cooling chamber 2 where controlled cooling can be achieved by means of external or internal water sprays (not shown), cooling gas jets or other means. Many desired reactions have been found to occur when the reactants have cooled to about 2000°F, but this temperature is entirely dependent on the particular reactants and, as indicated previously, cooling is not essential in all cases. The furnace products, both solid and gaseous, pass directly from the reaction chamber and, as more clearly outlined in Figures 4 and 5 which are flow diagrams of the process, can be collected in a series of wet scrubbers and other conventional dust collecting equipment. The solutions and solids recovered from the gas handling system are processed for the recovery of metal values as refined metals or marketable compounds by conventional metallurgical techniques.

EXAMPLE 1

In the series of tests reported here a Leach Residue from Sherritt-Gordon Mines Ltd. was used as the raw material. This residue is a relatively complex waste product resulting from pressure leaching a Ni-Co concentrate and which still contains combined nickel and cobalt values in a form not previously considered recoverable.

TABLE 1

Representative Head Assay of Leach Residue

Nickel	(Ni)	0.85%
Cobalt	(Co)	0.19%
Copper	(Cu)	0.13%
Iron (total)	(Fe)	47.48%
Sulphur (total)	(S)	10.57%
Carbon	(C)	2.35%
Acid-Insolubles	(SiO_2 etc.)	21.90%

Prior to each test run, the furnace, (as shown in Figure 2), dust collection units and all internal surfaces were thoroughly cleaned to prevent contamination and ensure standard condition. The feed material was weighed into the feed hopper 31. The 400 Hz a.c. generators 53 (Figures 4 and 5) for the pre-ionizing and main units were started and synchronized. The pre-ionizing unit 14 was then started usually employing three of the 400 Hz generators and using argon gas as the plasma medium. When this operation became stable, the main ionizing unit was started usually employing seven of the 400 Hz generators and using air, nitrogen or hydrogen as the plasma and reactant gas. As soon as the operation stabilized, the feeder 57 was started and operated at a predetermined rate until the hopper 31 was empty. Upon completion of the run, all dry materials were collected from the entire apparatus, sampled and weighed and the scrubber solution volume was measured. The solution was allowed to settle overnight and the solid material was separated by filtering.

TEST 1

Feed processed	—	4540 grams
Feed rate	—	454 grams/minute
Gas on pre-ionizing unit	—	Argon at 10 S.C.F.H. (approx.)
Gas on main arc	—	CH_4 (natural gas) at 150 S.C.F.H.
Power Input	—	60 KW

TABLE 2

Furnace Products Reclaimed by Bag Filter

Approximate Metallurgical Balance

Material		Fe		Ni		Co		S		Insol	
	gr.	%	gr.	%	gr.	%	gr.	%	gr.	%	gr.
Feed.	4540	42.9	1948	0.75	34	0.19	9	11.7	531	17.7	804
Total Prod. ± Unaccounted	3859 681	47.5	1834 —114	0.85	33 —1	0.19	7 —2	10.7	413 —18	21.9	844 +40

The solid furnace products reclaimed in the bag filter were carefully sampled and 50 grams were leached for 16 hours at room temperature in an open bottle with 100 ccs ammonium
5 hydroxide (28% NH$_3$) and 25 gms. ammonium carbonate. This treatment showed that 66.6% of the nickel based on the feed assay could be extracted from the processed material by a simple leaching step (no pressure). It will be
10 remembered that the starting material is a nickel pressure leach residue and therefore that above result is extremely favorable and indicates that passage through the high enthalpy zone has achieved an extensive
15 solubilization of the nickel values in the pressure leach residue. As a double check on the efficacy of the treatment, similar leaching tests were performed on the pressure leach residue and under the best laboratory conditions it was found that only 23.7% of the 20 nickel could be solubilized.

Further tests were conducted to determine the effects of other reactants as listed below:

Test 2 25

This test was performed to ascertain whether the nickel values could be chlorinated, and rather than employ chlorine gas in the plasma zone, sodium chloride was added to the feed materials.

Operating Data

Feed processed	— 8172 grams (includes 2.5% NaCl)
Feed rate	— 450 gr./min.
Gas on pre-ionizing unit	— Argon at 10 S.C.F.H.
Gas on main arc	— Nitrogen at 150 S.C.F.H.
Power on main arc	— 50 volts, 1150 Amps., 400 Hz

Furnace products discharged directly to scrubber Results (see Table 3)

TABLE 3

	Feed		Products					
	%	Wt. Gms.	Slag	Dust	Scrubber Solids	Scrubber Solution	Gas	Unbalance
Fe	41.3	3375	446	610	2238	92		11
Ni	.79	65	8	13	35	5.		— 4
Co	.16	13	1.45	2.18	8.34	.9		—
Cu	.05	4	1	1	N.A.	.5		— 2
S	11.24	915	58	92	433	170	162	—
Na		109	10	15	—	88		4
Cl		167	—	N.A.	—	162		— 5
Remainder		3524	384	624	2047	356	162	49
		8172	909	1357	4761	874	324	53

From these results it can be seen that about 75% of the feed materials were collected either
35 in the scrubber as solids or as a dust at the bottom of the reaction chamber. Each of the products was sampled and, as before, subjected to an ammonium hydroxide leach. A nickel balance shows the effects of the plasma treatment on the leaching properties of the 40 products.

Nickel Balance

Fraction	Nickel in Grams	Grams placed in Solution on leaching with NH$_4$OH
Sample	65	—
Slag	8	.27
Dust	13	2.14
Solids	35	2.10
Solution	5	5.01
Gas	—	—
Unaccounted	4	—
	65	9.52

Placed in Solution—15%
Placed in solution by ammonium leaching from untreated head sample H—8— 26%

5   In this case the particular NaCl treatment did not make the nickel values in the residue significantly more extractable by a simple leaching technique.

Test 3

   A further test was conducted employing 10 hydrogen as the reactant gas in the main arc unit. No chlorine was added to the atmosphere in this case.

Operating Data

Feed processed	—	5618 gms.
Type	—	Sherritt Gordon Residue
Feed rate	—	490 gms./min.
Gas on pre-ionizing unit	—	Argon at 10 S.C.F.H.
Gas on main arc	—	Hydrogen at 150 S.C.F.H.
Power on main arc	—	55 Volts, 1150 Amps.

15 RESULTS (See Table 4 overleaf)
   It will be noted that once again a considerable proportion of the feed material was so severely affected by passage through the arc that it was transformed into a gas of particles 20 so fine that it was not retained in the recovery system. Applicant considers this a most surprising and significant feature. After passage through the arc zone the various products were recovered from different parts of the equipment and subjected to an ammonia leach with 25 the following results:

Nickel Balance

Fraction	Nickel in Grams	Grams placed in Solution by ammonia leach
Head Sample	47	12.31 gms. = 16.19%
Slag	2.78	.49
Dust A	20.97	3.69
Dust B	9.65	1.65
Fume	3.90	.73
Solution	.12	.12
Solution Solids	.16	.02
Unaccounted	9.42	9.42
	47.00	16.12 = 34.26%

As the head sample shows only 26.19% of the nickel. values can be recovered by an ammonia leach and up to 34.26% may be recoverable following the arc treatment; the arc treatment may produce increased solubilization of the nickel in the pressure leach residue material. Such result is of course contingent on the assumption that the "unaccounted" portion is in fact in the form of a gas which could be easily treated if a more elaborate recovery system, designed to catch gases, were employed.

TABLE 4

	Feed	Products							
	Wt. Gms.	Slag	Dust A	Dust B	Baghouse Fume	Scrubber Solids in Fluid	Scrubber Solution	Gas	Unbalance
Fe	2337	150	1089	485	160	12	1.3		—439
Ni	47	2.78	20.97	9.65	3.9	.16	.12		— 9.42
CaO	174	7	58	18	6	.5	18	7	— 59
S	617	36	255	115	56	2.34	20	132	—
Remainder	2443	116	1074	377	71	10.23	59.5	566	—169
	5618	312	2497	1005	297	25.23	99	705	—677

EXAMPLE 2

In the test reported here, a similar procedure was employed as that of Example 1 using Tulameen sand as the head material together with an NaCl addition as an alternative to using chlorine gas as the carrier.

The Tulameen material is from a river deposit ranging in size from gravel to fine sand and clay. Recent work using atomic absorption techniques has shown that this material bears values in gold, silver, platinum and other of the platinum group metals.

These metal values occur in part as very finely divided free metal, in part as free metal precipitated in a matrix of magnetite and/or chromite, and, it is believed, in part as mineralogical complexes.

There is also evidence that these sands carry values in other "heavy" minerals such as euxenite, columbite, monazite, rutile, ilmenite, chromite, magnetite, etc. By known ore-dressing techniques, a complex heavy concentrate can be recovered. To process this complex concentrate by conventional extractive metallurgical techniques for the optimum commercial recovery of the metal values would be most difficult, tedious and expensive. Dissociation of the complex minerals in the high energy environment characteristic of a plasma and the reformation of simpler compounds on a continuous basis offers the metallurgist a simpler approach for the recovery of more of the contained metal.

The sample of sand processed had a mesh size of about 100% through 30 mesh and an approximate head assay of:

Silica	(SiO_2)	33.13%
Iron	(Fe)	24.05%
Lime	(CaO)	5.42%
Magnesium Oxide	(MgO)	5.57%
Aluminia	(Al_2O_3)	7.35%
Sulphur	(S)	Trace
Sodium Oxide	(Na_2O)	3.75%
Gold	(Au)	0.11 oz ton/
Platinum	(Pt)	0.7 oz/ton

This sample was loaded into the feed hopper together with a 10% addition of NaCl designed to provide sufficient chloride ions
5   for the desired reaction. Alternatively, chlorine carrier gas could be used.

The pre-ionizing plasma 30 was started by striking an arc between electrodes 19 and 20 using about a 10 kW a.c. power supply from
10   3 motor generator sets 53. Argon was admitted under pressure via inlet 26 as the pre-ionizing plasma gas. When the pre-ionizing plasma arc was stabilized air was admitted via inlet 33 and inlets 29 and the main arc 15 was struck
15   between electrodes 9 using a 55 volt 1150 amp. 400Hz a.c. power supply from 7 motor generator sets 54 via an isolating transformer 55. A high voltage, low amperage, high frequency alternating current of 5 mHz from an oscillator
20   56 was superimposed on the main power supply in order to stabilize the arc. When the whole system had stabilized, the feeder 57 on the hopper 31 was started and the precious metals containing material was fed through the
25   rotary valve 32 to the mixing device 34, where

it was intimately mixed with the suspending carrier gas (air), from inlet 33, and carried to inlets 29 and thus injected into the arc zone 30 where the solid feed material and the carrier gas, in this case air, were raised to a   30 high energy level. The gas and solid flow was then passed between electrode tips 9, which were adjusted to permit maximum passage of material without extinguishing the arc. It was found that a feed rate of 330 gms./min. could   35 be achieved with an electrode spacing of 1/4" and a power supply of 60 kVA 400Hz when a 6 kW 5 mHz superimposed current was applied. The solid materials, suspended in the reaction gas were at least partially dissociated   40 in their passage through the high intensity zone and tail flame plasma stream 16, and were permitted to cool in reaction chamber 2 to enable the chemical reactions to take place. Some cooling gas was injected into the reaction   45 chamber to effect control of the temperature within the chamber. The products of the reaction were recovered from the conventional scrubber 38 and were assayed as follows:

Analysis of Products

		Slag	Dust	Scrubber Solids	Scrubber Solution
Silica	(SiO_2)	30.18%	30.42%	38.93%	86 p.p.m.
Iron	(Fe)	29.51	28.25	25.11	45
Calcium Oxide	(CaO)	5.20	5.12	4.72	21
Magnesium Oxide	(MgO)	5.47	5.52	5.86	25
Alumina	(Al_2O_3)	6.20	4.40	6.75	132
Sulphur	(S)	0.61	0.86	1.31	195
Sodium Oxide	(Na_2O)	2.50	3.68	1.25	430
Gold					0.08
Platinum					0.3

or, expressing these figures as grams of product recovered in each section: (see Table 5)

TABLE 5

	Feed		Products					
	%	Wt. Gms.	Slag	Dust	Scrubber Pulp	Scrubber Solution	Gas & Un-Balance	% Missing
Fe	24.05	921	67	177	113	9	558	60.3%
SiO_2	33.13	1268	69	190	175	8	826	65.1%
CaO	5.42	208	11	32	21	3	141	67.8%
MgO	5.57	213	12	34	27	3	137	64.3%
Al_2O_3	7.35	286	14	28	31	15	198	69.2%
Sodium		160	4.3	17	5	64	69	43.1%
Chlorine		246	—	N.A.	—	130	116	47.2%
S	Trace	—	1.4	5.6	5.9	39	52	
O_2		351E	19E	71E	43E	78E	140E	
Unknown		177	29	70	29	3	46	
		3830	227	638	450	352	2163	
Platinum		0.09183gms.				0.06gms.		
Gold		0.0144gms.				0.016gms.		

It will be appreciated from the results of this test that significant changes have occurred during the passage through the high intensity zone. A small amount of slag from which all volatile chlorine has been removed is produced, together with a quantity of dust which represents material which did not go through the high intensity zone or at least was not markedly affected. Due to the design of the equipment a certain amount of dust resulted from material which bounded off the electrodes and did not fall through the high intensity zone. The scrubber pulp represents material, which is insoluble but is sufficiently coarse to be caught in the scrubber, is primarily the residue from silicate sands of the feed. The scrubber solution represents material which has gone through the arc and has solubilized. It will be noted that a very large percentage of the feed chlorine appears in the scrubber solution, and hence it may be said that considerable chlorination of the sands has occurred. It will be further noted that the precious metals, gold and platinum, occur in the scrubber solution. Gold is, in fact, present to the extent of in excess of 100% of the assay of the initial feed material, a discrepancy which may be explained by inaccuracies attendant on the assay procedure. Platinum appears in an amount corresponding to 65% of the platinum in the feed assay and applicant considers this significant evidence that there has been a selective chlorination of the precious metals on passage through the arc. A considerable volume of gas was generated in the reactions and it will be observed that there is a considerable unbalance of the output when compared to the input. This unbalance is either a gas or very finely divided particles produced in the arc which are not trapped by the scrubber and are lost in the exhaust system. This may be significant when it it appreciated that the relatively coarse feed materials have been reduced to a dimension too small to be trapped in a relatively efficient gas scrubbing system. Clearly severe changes have been effected.

The most significant result of the above test is the indication that the precious metal values in the tested alluvial sand which heretofore were difficult to recover have been converted from insoluble to soluble form in the presence of large amounts of iron and other metals in the ore on passing through the described apparatus.

In considering the test results obtained in all of the above tests it will be appreciated that a new and highly useful method of treating ore has been developed. By this process nickel in commercially attractive amounts has been recovered from residues which have been previously treated by the most efficient means known to metallurgists at the present time, namely pressure leaching for the extraction of nickel. Similarly, precious metals (gold and platinum) have, by passing the host material through a highly enthalpy environment with NaCl as a selected reactant, been put into a form (water soluble) much more amenable to recovery by conventional means than would be the case if the same host material were to be processed by the normal metallurgical techniques. At the same time, other metals present in the host material as complex heavy minerals, and having commercial value are also made recoverable. In addition to these recoveries the present process can be applied to many other metallurgical reactions, such as those enumerated hereinabove.

WHAT WE CLAIM IS:—

1. A process for heat treating a non-gaseous material including providing a controlled atmosphere, establishing a high enthalpy thermal environment (as hereinbefore defined) in said atmosphere, by means of at least one high-intensity arc (as hereinbefore defined), the or each said arc having an elongated tail flame forming part of said environment, feeding said material in powder form into said controlled atmosphere for passage through, and with a sufficient residence time in, said environment to affect the material by the heat therein, and allowing the material to pass from said environment through a cooling atmosphere to a collection zone.

2. A process as claimed in claim 1 wherein said material is passed through said environment substantially along the longitudinal axis thereof.

3. A process as claimed in either preceding claim wherein the or each said arc is established between more than two electrodes.

4. A process as claimed in any preceding claim wherein each electrode is made of a carbon-containing material.

5. A process as claimed in any preceding claim wherein said electrodes are energised by alternating current.

6. A process as claimed in any preceding claim wherein a plasma carrier gas is injected into said high enthalpy environment.

7. A process as claimed in claim 6 wherein said material is suspended in said carrier gas for introduction into said high enthalpy environment.

8. A process as claimed in claim 7 wherein the suspension of said material in said carrier gas is injected into a low-intensity plasma to produce an at least partially ionised stream of gas containing said suspended material before being introduced into said high enthalpy environment.

9. A process as claimed in any of claims 6 to 8 wherein said carrier gas is selected so as to take part in a chemical reaction with the material introduced into said high enthalpy environment.

10. A process as claimed in claim 8 or 9 wherein said low-intensity plasma stream is

produced between a pair of spaced electrodes, the gap between the electrodes being supplied with a second carrier gas.

11. A process as claimed in claim 10 wherein said second carrier gas is an inert gas.

12. A process as claimed in any of claims 9 to 11 wherein the first-mentioned carrier gas is or includes a halogen, or a halide, or hydrogen, or oxygen, or nitrogen, or natural gas or air.

13. A process as claimed in any preceding claim wherein the heat treatment of said material produces one or more of the following chemical reactions: the conversion of metal oxides to metal; of metal oxides to metal halides; of metal halides to metals; or the dissociation of complex minerals to simple compounds.

14. A process as claimed in any preceding claim wherein said material may be an ore, a concentrate, or a residue.

15. A process as claimed in claim 13 or 14 wherein a desired metal or metal compound is separated from other compounds produced as a result of the passage of the flowable material through said high enthalpy environment.

16. A process as claimed in any preceding claim wherein said material contains nickel and is subjected to an ammonia leaching operation after it has passed through said collection zone.

17. A process for heat treating a non-gaseous material substantially as hereinbefore described in the Examples.

18. A process for heat treating a non-gaseous material substantially as hereinbefore described with reference to and as shown in Figures 2—5 of the accompanying drawings.

19. Apparatus for carrying out the process claimed in claim 1, said apparatus including a chamber for containing a controlled atmosphere, means for establishing at least one high-intensity arc (as hereinbefore defined) to establish a high-enthalpy thermal environment in said atmosphere, means for feeding a material in powder form into said environment, and means permitting the said material to pass from said environment through a cooling atmosphere to a collection zone, the

or each said arc being produced between spaced electrodes, there being electric power means for energising said electrodes to produce the or each said arc, at least one of the said electrodes including carbon-containing material.

20. Apparatus as claimed in claim 19 wherein the feeding means includes a first passage for introducing particulate material into said said chamber and a second passage for introducing into said chamber a carrier gas for conveying said particulate material along a flow path through said environment.

21. Apparatus as claimed in claim 20 wherein there is a pre-ioniser for at least partially ionising material introduced through said passages prior to entry into said high enthalpy environment.

22. Apparatus as claimed in any one of claims 19 to 21 wherein means for cooling the material is provided for cooling the material after its passage through said high enthalpy environment and prior to its entry into said collection zone.

23. Apparatus as claimed in any one of claims 19 to 22 wherein said power means includes an a.c. power supply for energising said electrodes to produce the or each high intensity arc discharge.

24. Apparatus as claimed in claim 23 wherein the power supply to the electrodes is such that they are over-powered and at least partially vaporised.

25. Apparatus as claimed in claim 23 or 24 wherein stabilising means are provided for stabilising the said arc(s).

26. Apparatus as claimed in claim 25 wherein said stabilising means includes the superimposing of a high voltage, high frequency, low amperage current on the power supply.

27. Apparatus as claimed in any of claims 19 to 26 substantially as hereinbefore described with reference to and as shown in Figures 2—5 of the accompanying drawings.

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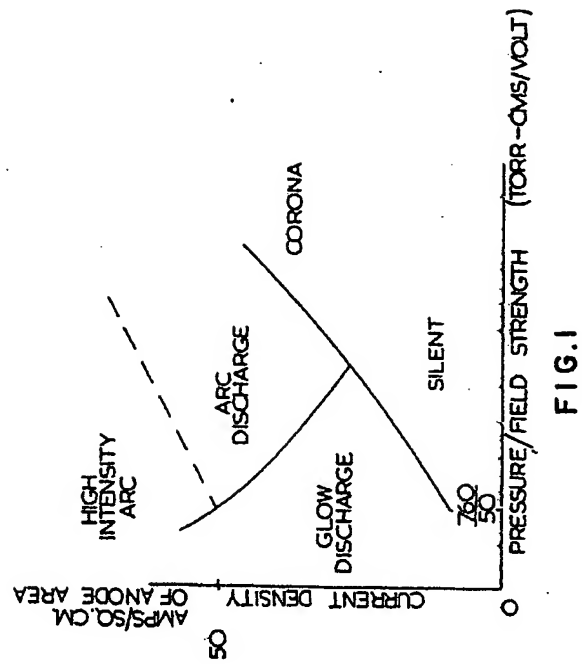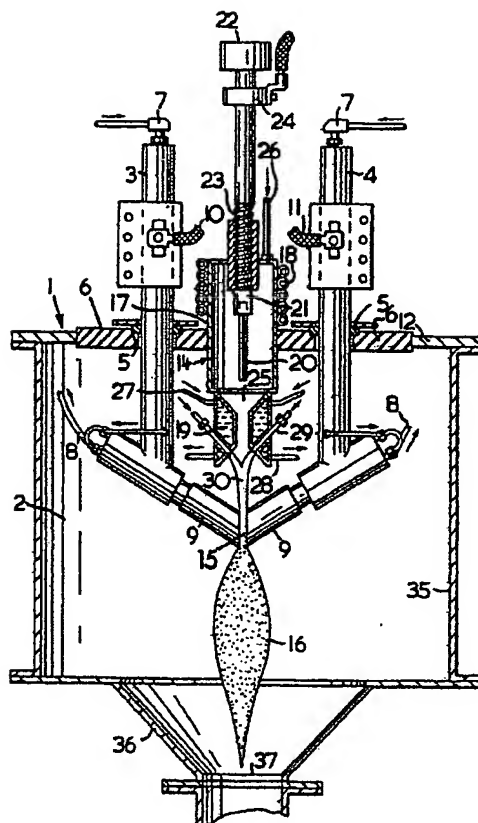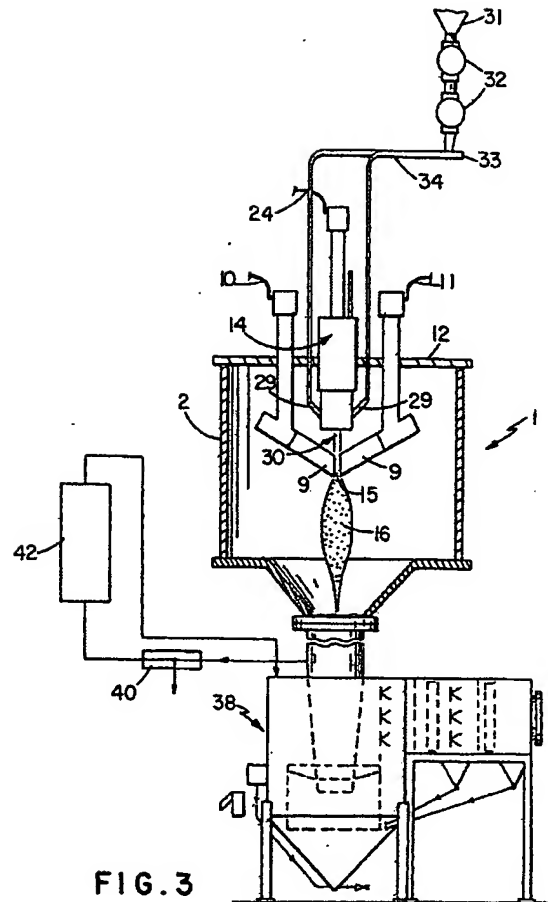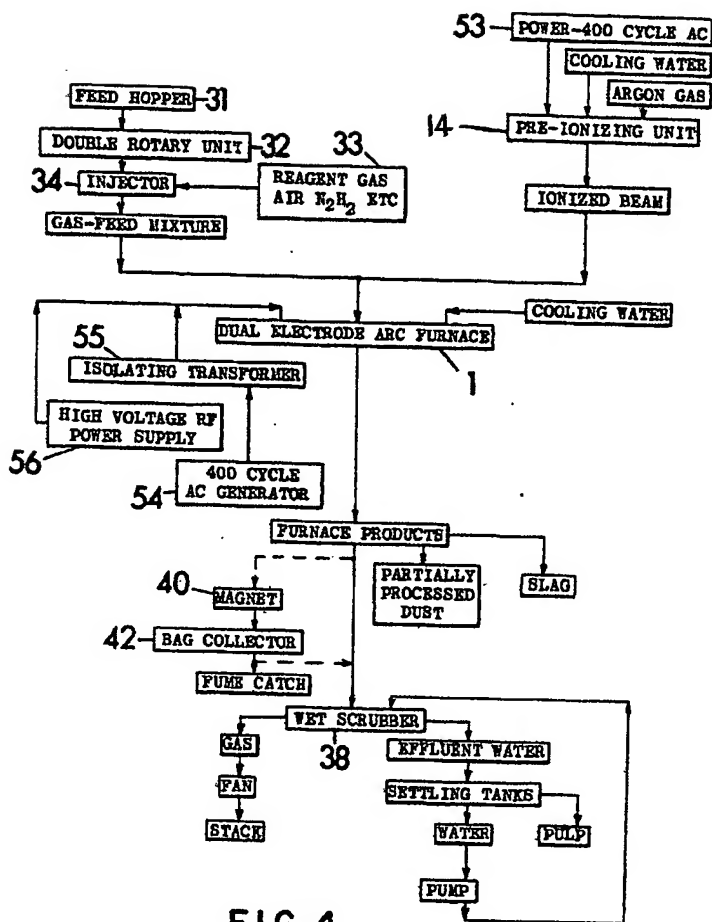262 High Holborn,
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FIG. I

FIG.2

FIG.3

FIG.4

FIG.5